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# Effect of Nail Pitch on the Shear Performance of Nailed GLT-plywood Specimens\*<sup>1</sup>

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**Abstract**—Nails, used without predrilling holes in the wood, prevent the decrease of slip modulus by their clearance at the predrilled hole as like bolt fastening. For the purpose of investigating the effect of nail pitch on the shear properties of nailed plywood-sheathed glued laminated timber (GLT) specimens. Double sided single shear tests were conducted by varying nail pitch from 50, 75, 100 mm, and to 150 mm.

The slip displacements measured at three different place, i.e. upper, bottom and center, were almost same. It was concluded from this experiment that the slip modulus were not affected by the nail pitch and showed that there were big dispersions on the observed values. The yield strength showed constant values despite of nail pitch. The maximum strength increased slightly as the nail pitch increased.

Judging from these experimental results, it might be concluded that the effect of nail pitch on the shear performance of nailed plywood sheathed GLT specimen could be ignored, thus from the practical point of view, nail pitch has no significant effect on the design calculation.

**Keywords** : slip modulus, shear properties, nail pitch, plywood-sheathed shear wall

## 1. Introduction

Nails are generally used when loads are relatively light. They are used for light-frame construction, diaphragms, and shear walls<sup>1)</sup>. Nailed fastening, the most frequently used without predrilling holes in the wood, have some merits that are easy to apply to the wood by hand with hammer and has no initial slackness which brings decrease of initial stiffness as shown in bolted timber joints due to the clearance of predrilled hole.

Studies<sup>2-11)</sup> on nail joints have gotten many results, understanding properties of nail itself and several nailed fastening<sup>2)</sup>, and theoretical utilizations<sup>3-11)</sup>. Nailed fastening is one of the safest fastening, because its good ductility permits large deformation even if large load act on the nailed fastening. Furthermore, allowable strength of nail is not affected by anisotropic properties<sup>12,13)</sup>.

The light-frame construction is mainly using nails to fasten the frame and shear walls, which are sheathed by plywood or structural composite boards. In this construction, since most load transmission of member to member depends heavily on the shear resistance and the withdrawal resistance of nail, each nail plays an important role in safety of total system. Therefore, it is important for the design of nailed fastening to use proper size, to drive on proper point, and to drive with proper spacing<sup>1)</sup>.

Shear strength of shear wall is able to estimate approximately when rigidity of sheathed wall and shear performance of nail are known. In case of nailed shear

wall fastened by nail on glued laminated timber (GLT) as frame and plywood or oriented strand board (OSB) as sheathed wall, shear rigidity ( $K$ ) of shear wall can be calculated by using slip modulus ( $K_s$ ) of each nail and yield strength ( $Q_a$ ) of shear wall can be calculated by using yield strength ( $P_y$ ) of each nail.

In recently, in the case of three stories wooden construction especially, for increasing strength of nailed shear wall, it is often conducted to drive more nails than the amount assigned by the design code<sup>14)</sup>. In this case, the effects of nail pitch on shear properties of the wall had to be checked. But, the effects of nail pitch on the shear properties of shear walls had not been conducted so much up to date.

Therefore, in this study, for examining the effect of nail pitch on the shear properties of nailed plywood sheathed GLT specimens, compression type shear test were conducted.

## 2. Theory

The yield shear strength ( $P_y$ ) per unit length on the sheathed shear wall without openings is given as equations (1), (2) taken into consideration of nail arrangement<sup>14,15)</sup>.

$$P_y = q \cdot s \quad (1)$$

$$s = \min \left[ \frac{m-1}{a}, \frac{n-1}{h} \right] \quad (2)$$

where,

$q$  is yield strength of a nail in kN (in this study, maximum strengths were used)

$a$  and  $h$  are width and height of shear wall in mm, respectively

$m$  and  $n$  are number of nails in width and height direction in shear wall, respectively

In addition, the value of  $q$  could be obtained from experimental results<sup>14)</sup> of single shear test of nailed joint specimens and calculated from equations (3), (4) using yield

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strength ( $F_y$ ) of nail and bearing stress ( $F_{e1}$ ,  $\sigma_e$ ) of sheathing material<sup>14)</sup>.

$$q = C F_e d_n t \quad (3)$$

$$C = \left[ 1, \sqrt{\frac{2\beta(1+\beta)}{(2-\beta)^2} + \frac{2\beta\gamma(d_n/t)^2}{3(2+\beta)}} - \frac{\beta}{2+\beta}, \frac{\beta_n}{t} \sqrt{\frac{2\beta\gamma}{3(1+\beta)}} \right] \quad (4)$$

where,

$d_n$  is diameter of nail in mm

$t$  is thickness of side member in mm

$\beta$  is ratio of the bearing strength of main member to that of side member ( $F_{e2}/F_{e1}$ )

$\gamma$  is ratio of the bearing strength of main member to yield strength of nail ( $F_y/F_{e1}$ )

$F_y$  is characteristic yield strength of nail in MPa

### 3. Materials and Methods

In this study, nail pitch varies 50, 75, 100, and 150 mm. Loading type is compressive shear test, showing

representative diagrams in Fig. 1, in which 150 mm nail pitch can be seen, respectively.

Common nails, CN50, were driven into side member by hand so as to prevent excessive embedment. For the sheathed material, 9 mm plywood was used. For the main member, douglas-fir GLT was used. The sizes of specimens are different each other since their end and edge distance were taken enough.

Table 1 shows specifications of tested specimens, nailed fastening.

The slip displacements of nailed fastening were measured at three points, namely at the center (#5, #6), upper (#3, #4), and lower (bottom; #7, #8) point as shown in Fig. 1. In addition to these, absolute displacements of main member (#1, #2) and side members (#9, #10) were also measured. The comparative slip measurement at upper and bottom points were only done on two specimens of total six replications. Total slip displacement ( $S$ ) of specimen were calculated in equation (5), by subtracting slip deformation of side member from that of main

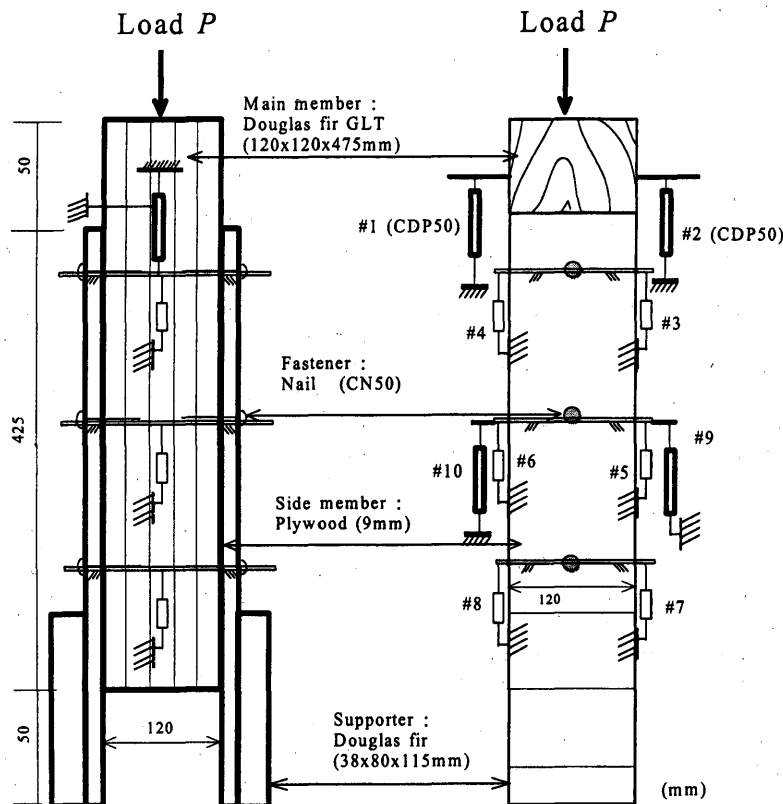


Fig. 1. Schematic test method of nailed fastening (nail pitch 150 mm). #1, #2, #9, #10; deformation measurement device for 50 mm. #3-#8; deformation measurement device for 20 mm.

Table 1. Specifications of tested specimens.

Specimen	Main member (Side member)	Density ( $\text{kg/m}^3$ )		Nailing pitch (mm)	Nailing condition	Nails	Replications
		Main member	Side member				
PW150	Douglas fir GLT (9 mm plywood)	406	388	150	in a row	6	6
PW100		368		100		8	
PW75		357		75		10	
PW50		407		50		14	

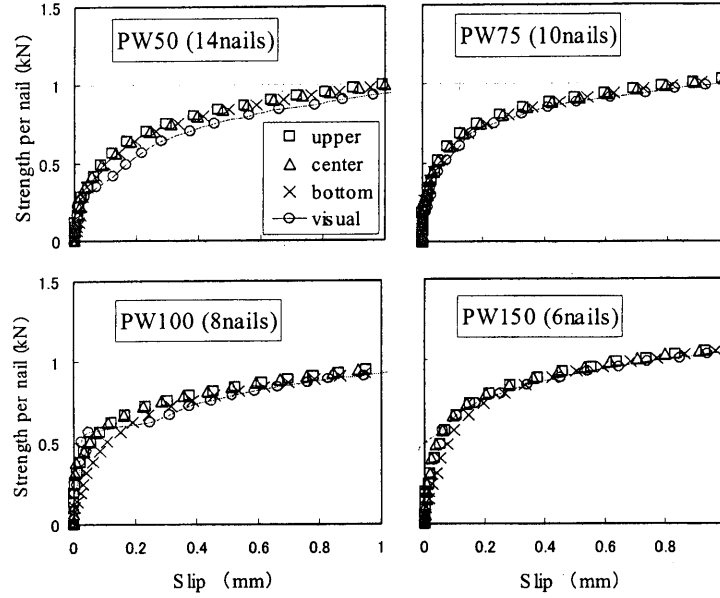


Fig. 2. Relationship between strength per nail and slip displacement. Upper: slip of nail fastening on top of 3 divided point. Center: slip of nail fastening on center of 3 divided point. Bottom: slip of nail fastening on lower of 3 divided point. PW50: specimen name of 50 mm nail pitch. PW75: specimen name of 75 mm nail pitch. PW100: specimen name of 100 mm nail pitch. PW150: specimen name of 150 mm nail pitch.

member.

$$S = \frac{(\#1 + \#2) - (\#9 + \#10)}{2} \quad (5)$$

#### 4. Results and Discussion

##### 4.1 Differences slip displacement by the locations of measurement

From the results of shear test on nailed fastening, the relationship between shear force per nail and slip displacement measured at various location up to 1 mm slip are shown in Fig. 2. In this figure, the value, “visual”, indicates the absolute slip displacement as defined in equation (5).

As shown in Fig. 2, the slips measured at the bottom location of the 100 mm nail pitch (PW100) and 150 mm nail pitch (PW150) specimens looks like larger than those measured at another two points. But, compared with the visual slip, these values seemed to be experimental deviations. The disorder of the visual slip at initial region, is seemed to be the problem due to settlement of test specimen at the first stage. As slip deformation increases with increasement of the load, both relative and visual slip displacements were converged to a similar load-slip relationship in all specimens.

According to the theoretical analysis, it is considered that the stress of nailed fastening is distributed severely at bottom and upper nail than those of center, but, from these experimental results, we might be concluded that the average slip deformation are constant for being located at anywhere.

##### 4.2 Nail pitch and slip modulus

The slip moduli ( $K_s$ ) were obtained by applying the least square method on the initial load-slip data shown in

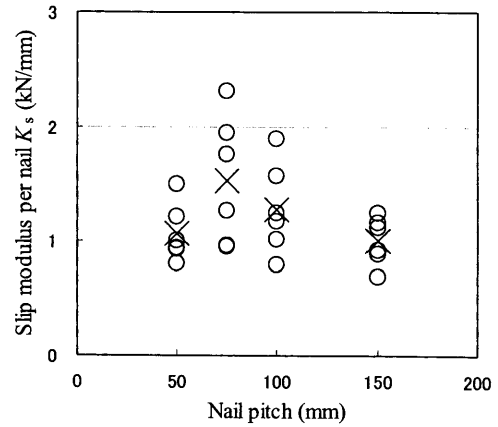


Fig. 3. Relationship between slip modulus ( $K_s$ ) per nail and nail pitch.  $\times$ ; average value.

Fig. 2. Fig. 3 shows the effects of nail pitch on slip modulus. Totally, the slip modulus decreases as nail pitch becomes larger, but almost the same values are obtained from 50 mm nail pitch (PW50) until 150 mm nail pitch (PW150). Therefore, in this study, we can be concluded that the effects of nail pitch on slip modulus are not clear. It is considered that the disorder of slip displacement in initial region, as explained previous chapter, makes dispersion of slip modulus.

##### 4.3 Nail pitch and yield strength

Fig. 4 shows the relationship between yield strength per nail and nail pitch from the results of single shear test on double-sheathed nailed joint specimens.

In this study, the yield strength per nail shows constant value without respect to the nail pitch.

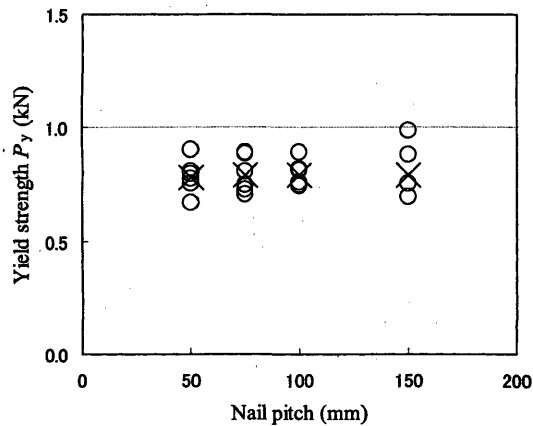


Fig. 4. Relationship between yield strength ( $P_y$ ) per nail and nail pitch.  $\times$ ; average value.

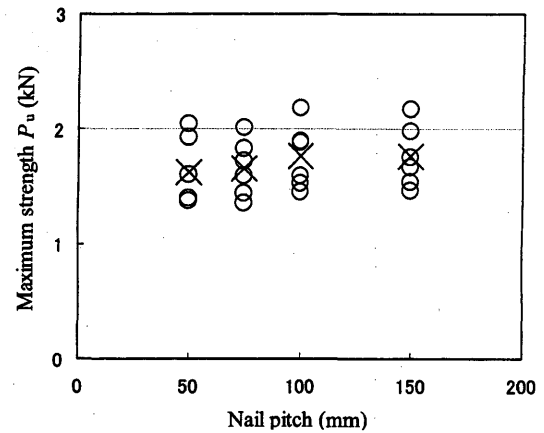


Fig. 5. Relationship between maximum strength ( $P_u$ ) per nail and nail pitch.  $\times$ ; average value.

Table 2. Nail shear strengths by double sided single shear test with several nail pitch.

Specimen	Values per nail			Nails	Nail pitch
	Slip modulus $K_s$ (kN/mm)	Yield strength $P_y$ (kN)	Maximum strength $P_u$ (kN)		
PW50	1.07 (0.25)	0.78 (0.08)	1.62 (0.29)	14	50
PW75	1.53 (0.56)	0.79 (0.08)	1.66 (0.25)	10	75
PW100	1.28 (0.39)	0.79 (0.06)	1.76 (0.27)	8	100
PW150	1.00 (0.21)	0.79 (0.12)	1.76 (0.26)	6	150

Parentheses is S.D.

#### 4.4 Nail pitch and maximum strength

Fig. 5 shows the relationship between maximum strength per nail and nail pitch. Table 2, also, shows the results of all specimens. From Fig. 5 and Table 2, the maximum strength per nail increases slightly as nail pitch increases, but in case of 100 and 150 mm nail pitch, the maximum strength values showed almost same.

It will be necessary to examine whether these slip modulus and strength values could be usable for estimating actual shear performance of the full scale nailed plywood sheathed shear walls<sup>16)</sup>.

Table 2 shows average values and standard deviations (S.D.) of shear test on nailed specimens with 6 replicates. Average yield strength per nail on all specimens showed 790N, and S.D. showed small dispersion, contrary to the large dissipation in slip modulus.

#### 5. Conclusion

Single shear test on double-sheathed nailed plywood GLT specimens with four types nail pitch, 50, 75, 100, and 150 mm, were conducted for investigating the effect of nail pitch on the shear performance of nailed joints. From the results, following conclusions were obtained;

- 1) To investigate the difference of slip displacements due to measurement point, relative slip displacement at three points were measured. The slip displacement at each point were all the same.
- 2) The slip modulus were not affected by the nail pitch and showed big dispersions.
- 3) The yield strength were also constant without respect to nail pitch.

4) The maximum strength increases slightly as nail pitch increases. But, it reached constant value as nail pitch became more than 100 mm.

5) Judging from a practical point of view, it will be concluded that shear performance of nailed plywood sheathed GLT specimen has no effect from nail pitch.

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